Fifth International Information Exchange Forum
on
"Safety Analysis for Nuclear power Plants of VVER and RBMK Types"
16 - 20 October, 2000; Obninsk, Russia

Investigation of the condensing pools behavior in the Accident Localization System of Ignalina NPP

S. Rimkevicius, E. Urbonavicius, B. Cesna
Lithuanian Energy Institute, Laboratory of Nuclear Installation Safety
Breslaujos 3, LT-3035 Kaunas, Lithuania

Introduction

Accident Localization System of Ignalina NPP is so called "pressure suppression" type containment. It means, that ALS uses condensing pools, which condense the main part of the released steam in order to reduce the peak pressures that can be reached during any LOCA. Conditionally ALS could be divided into at least two major volumes – dry well and wet well. The water pools separate these volumes. When the steam enters the first section (i.e. dry well volume), the pressure rises, and in order to reach the second section (i.e. wet well volume), the steam-air mixture must "bubble" through the water. This condenses most of the steam, reducing the peak pressure attained. Consequently, the design pressure in compartments before and behind condensing pools is different (Figure 1).

Thus, the condensing pools perform pressure suppression function and play an important role in thermalhydraulic parameters behavior in the ALS compartments during the loss of coolant accident. The main attention in this paper is concentrated to the investigation and assessment of phenomena concerning the pressure suppression function fulfillment during Maximum Design Basis Accident – rupture of pressure header of Main Circulation Pumps.

Description of pressure suppression system at ALS of Ignalina NPP

Accident Localization System consists of a series of reinforced enclosures. Generic descriptions of the ALS are provided in the Ignalina NPP safety analysis report [1] and in the source book [2]. Since the primary system consists of two symmetric circuits, the ALS is also divided into two almost identical parts. Only one ALS side (left side) is represented schematically in the Figure 1, the right side is almost symmetrical.

The condensing pools at Ignalina NPP are located in two similar in design ALS towers. These towers are adjacent to the system of reinforced leaktigh compartments (*3* and *4* in Figure 1). The main circulation pumps, suction and pressure headers of MCP, the group distribution headers, other piping and major components of the Reactor Cooling System are located in the reinforced leaktight compartments of ALS.

Each ALS tower houses five vertically positioned condensing pools. The pools contain the water reserves needed for condensation of the steam released in case of LOCA event. Air passageways *1* to the gas delay chamber *2* connect the spaces above the pools.

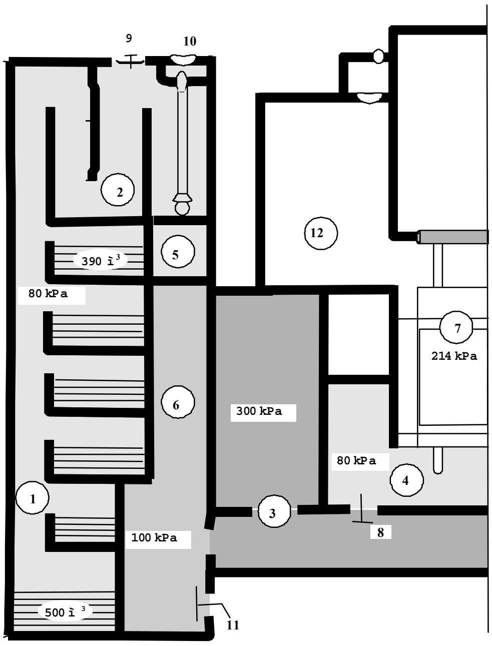

Figure 1: Design pressures in ALS compartments and in reactor cavity

1 Air Corridor
2 Gas Delay Chamber
3 Reinforced Leaktight Compartments
4 Lower Water Piping Compartment
5 Top Steam Reception Chamber
6 Bottom Steam Reception Chamber and Steam Distribution Corridor
7 Reactor Cavity
8 Steam Relief Valves (Burst Disks)
9 Lift-up Panels
10 Blow out Panels
11 Vacuum Breakers
12 Drum Separators Compartment

The bottom four condensing pools are intended for the condensation of steam discharged in the case of LOCA in leaktigh compartments of ALS (*3* and *4* in Figure 1) and in the case of multiple pressure tubes rupture in the reactor cavity *7*. A schematic diagram of the first four condensing pools (numbering from the bottom) is shown in Figure 2. The height of the overflow barrier (2.1 m) was chosen in the design by considering the expansion of the water caused by the bubbling of the steam. To maintain the water level of 1.1 m, there are two holes of 50 mm diameter in each overflow barrier of the condensing pool. Two rectangular holes, distributed at a height of 1.2 m in each overflow barrier, allow the condensate overflow and spill into the hot condensate chamber in the case of water level increase in the condensing pool.

The bottom four condensing pools are all similar, except the bottom pool, which is of somewhat smaller volume. The steam reception chamber takes up part of the cross-section of the bottom pool. In each pool of 2, 3 and 4 level, there are 10 steam distribution devices, each about 20 m long. The bottom pool has 7 devices 20 m long, and 3 devices 10 m long. The steam distribution devices are 800 mm diameter pipes connected to rectangular, sheet metal downcomers (vent pipes) that under normal operation conditions are submerged to a depth of 0.85 – 1 m in the water of condensing pools. At the exit end the vent pipes are provided with a saw-tooth edge in order of better steam distribution and reduction of condensation type oscillations.

The fifth (top) pools in both ALT are intended for the condensation of steam from steam relief devices of Reactor Coolant System. The steam from steam relief devices (SDV-A and MSRV) is directed to the Top Steam Reception Chamber and further to the steam distribution devices. TSRC divides the 5th condensing pool into two parts symmetrically. The structure of the steam distribution devices is analogous to those described earlier.

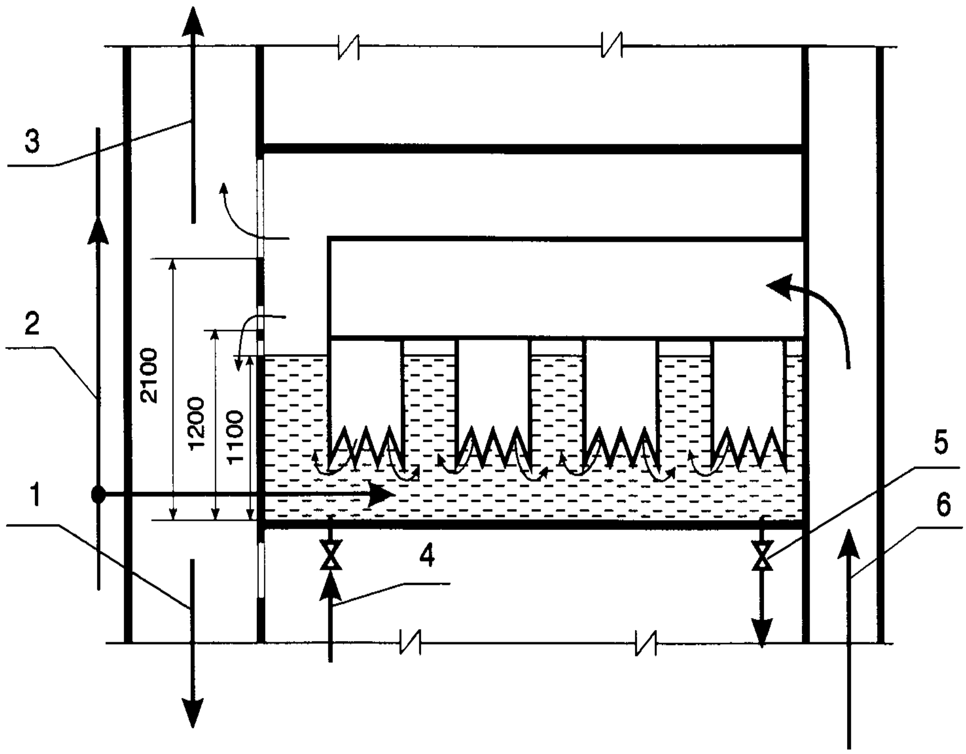

Figure 2: Condensing compartment and pool

1 - condensate overflow to Hot Condensate Chamber, 2 - cooled water supply, 3 - air and non-condensing gas removal to gas delay chamber, 4 - water supply for filling first condensing pool, 5 - water to purification system, 6 - contaminated steam from steam reception chamber

The fifth condensing pool of the left ALT is additionally intended for the condensation of steam from the reactor cavity in case of pressure tube rupture. Therefore, fifth pool of the left ALT is equipped with two additional 7.5 m long steam distribution devices. These devices have vent pipes submerged 1.5 m deep under the water. The steam is supplied from the reactor cavity to the steam distribution devices from above, by a 600 mm diameter pipe.

To avoid the boiling of the water in the condensing pools the Condensing Tray Cooling System provides the water to these pools. Water is provided to the headers for cooled water distribution. The description of the CTCS is provided in [1, 2].

Analytical investigations of phenomena related to pressure suppression function

The main phenomena, related to the pressure suppression function performance by condensing pools are the following:

1. Clearing of the initial water leg from the vent pipe;
2. Condensing pools water swelling and overflow;
3. Steam condensation and air carry over.

The code RALOC [3] was applied for the assessment of the phenomena related to the pressure suppression function. The model of the pressure suppression system, and separate phenomena (vent clearing, pool swell, condensation oscillations) that are included in this model, are validated by a large number of experiments, performed at Marviken, JAERI, GKSS, GKM test facilities. However, the construction of steam distribution devices at Ignalina NPP differs from these test facilities or from such devices at BWR in the following respects:

- the distance from the outlet of vent pipes to the pools bottom is less (0.1 m);
- the pool water depth and vent pipes submergence depth (~1 m) are smaller;
- the vent pipes have rectangular cross section for flow.

The first attempts to verify and validate the DRASYS code (essentially the same model of the pressure suppression system as used in RALOC) were undertaken for the pressure suppression system of Ignalina NPP in 1996 in the frames of a project between GRS (Germany) and LEI [4]. The results of SDV-A test were applied for the validation. Five short-term steam releases were performed to the fifth condensing pool of left ALT during this test. The comparison of measured and calculated pressure histories showed good agreement (Figure 3). No measurements of pressure during test was performed in first 4 seconds and in time period from 13 to 32 seconds because of steam release absence in these time periods.

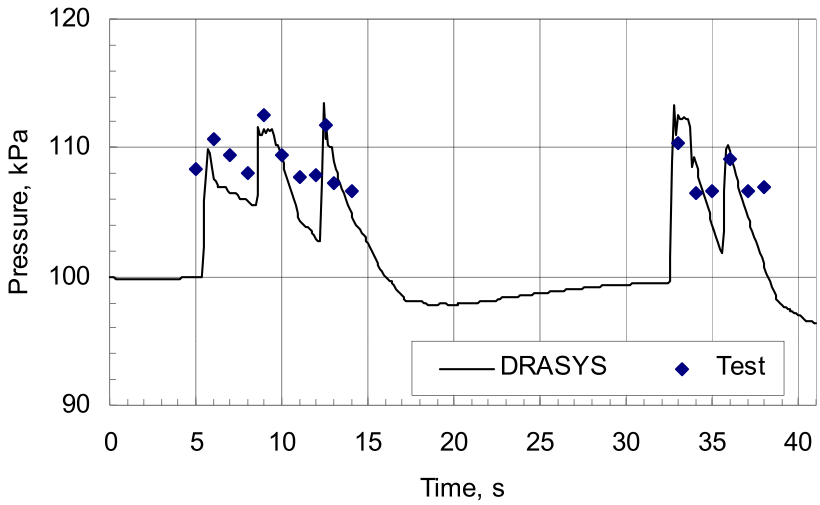

Figure 3: Comparison of calculated and measured pressures in the top steam reception chamber

Unfortunately, there is not enough data of experiments or tests for the analysis of ALS condensing pools and steam distribution devices performance, especially for large LOCA accident parameters. The data available from above-described test is considered to be insufficient and not detailed for validation of all relevant parameters and phenomena. Consequently, some uncertainty exists in the results obtained investigating the pressure suppression function performance at ALS of Ignalina NPP.

The results of analytical investigations of the phenomena related to pressure suppression function fulfillment in case of MDBA (break of pressure header of MCP) are presented below in this paper. The ALS model for RALOC code was developed in the frames of collaboration project between GRS (Germany) and LEI [5, 6] was applied for the analysis. The functions of mass and energy release from the break applied in this analysis are presented in [6]. These functions were calculated employing code RELAP5/MOD3.2 [8].

Clearing of the vent pipes of steam distribution devices. The vent pipes of steam distribution devices are inserted under the water of condensing pools. In the normal operation conditions the water level in the vent pipes is approximately at the same elevation as in the condensing pools, because the pressures are similar in dry well and wet well (i.e. in the volumes before and behind pools). When LOCA starts the water level in the vent pipes is driven by the steam gas mixture from the pressurized dry well. The vent clearing stage ends when the gas/water interface reaches the edge of the vent pipes.

The clearing of vent pipes in the case of MDBA can be seen from the gas/water interface position behavior calculated employing code RALOC. In the code RALOC assumed that interface position is 0, if water level is at edge of the vent pipe (for specific tooth edge – at the center axis through toughs). The interface position is negative if water level is inside vent pipe. The positive interface value shows that interface position is outside vent pipe – i.e. the formation of a bubble at the edge and outside of vent pipe occurs and pool swell stage take place. Consequently, before an accident, or at initial time of an accident, interface position is equal to vent pipe insertion depth. Vent clearing stage ends when the gas/water interface reaches the edge of vent pipe – i.e. at 0.5 s in the condensing pools of the left ALT and at 0.8 s at the right ALT (Figure 4). Faster vent pipe clearing at the left ALT is caused by a closer break location – MDBA was assumed on the left side of the reactor.

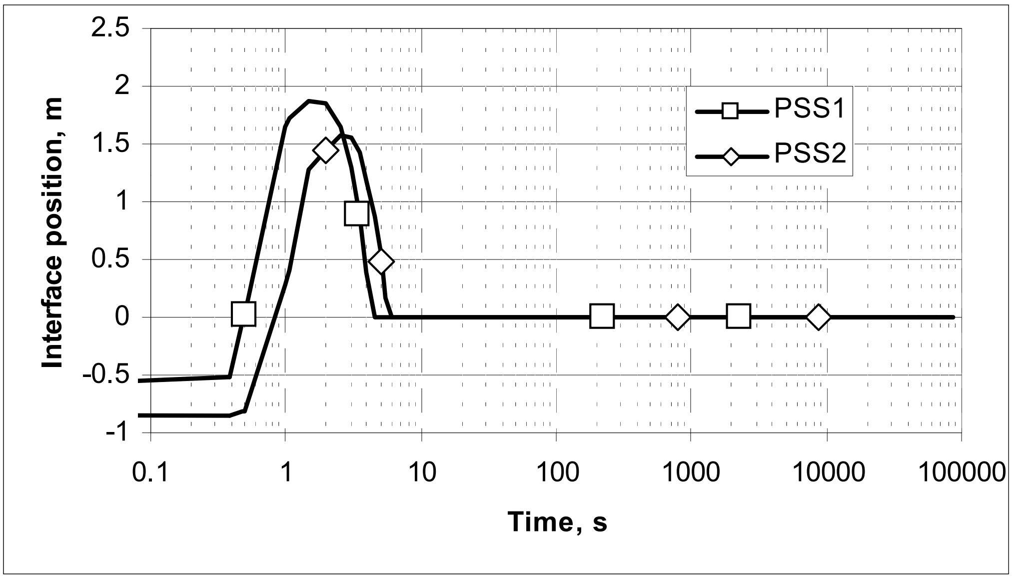

Figure 4: Behavior of interface position in the condensing pools of left (PSS1) and right (PSS2) ALT in the case of MDBA

Pools swell and overflow. The poll swell stage is characterized by the formation of a bubble at the edge of vent pipes. Consequently, this bubble grows outside vent pipes and lifts up the water layer. The results of calculations showed, that the water layer is lifted approximately by 1.8 m in the condensing pools of left ALT and approximately by 1.6 m in the right ALT (Figure 4). The water surface during pool swell stage reaches about 2.8 m from the pool bottom in the left ALT and about 2.6 m in the right ALT (Figure 5). The height of condensing pools is 3 m, so the maximum water surface elevation in the condensing pools of left ALT during pool swell stage was calculated close to the ceiling. The bubble collapses and the interface falls back after break through of non condensable gases. When the pool swell stage ends, the interface again reaches the edge of vent pipe – this occurs i.e. in 4–6 s after accident start.

Should be noted that not all the water in the condensing pools is affected by the pool swell. After the verification of DRASYS code for BWR reactors 80 % of radius (or 64 % of area) was recommended to assume as horizontal expansion radius in the pool swell process [3]. However, it is not known without special experiments, how much this expansion radius of bubble is suitable for the steam distribution devices at Ignalina NPP with RBMK-1500 reactor. The sensitivity analysis of expansion radius influence to the calculation results shows, that the significant lower expansion radius values lead to more conservative results. In the performed calculations of ALS it was conservatively assumed that 50 % of the total pool area is influenced by poll swell process.

The pool swell in Ignalina NPP pressure suppression system will lead to water overflow through the holes in the overflow barriers. However, the water overflow trough barriers due to pool swell is not simulated by the code RALOC. This assumption is reasonable because the pool swell process lasts only a few seconds and additionally the pool area is so large that in such a short time interval only a very limited mass of water may flow over.

The overflow holes are included in the calculation model, but overflow starts only if the water level, defined by the water mass in the pools, reaches these holes. Water mass in the condensing pools increases due to steam condensation and due to CTCS activation (the CTCS activation is assumed at 180 s after accident start and full capacity is reached in 120 s). When the water level (defined by water mass) reaches rectangular holes, it stops to increase, because water flows over from the condensing pools. The mass flow of water overflowing through the holes in barriers of condensing pools is presented in Figure 6. Almost 100 kg/s of water runs over through circular holes at 1.1 m and about 560 kg/s – through rectangular holes at 1.2 m from pools floor.

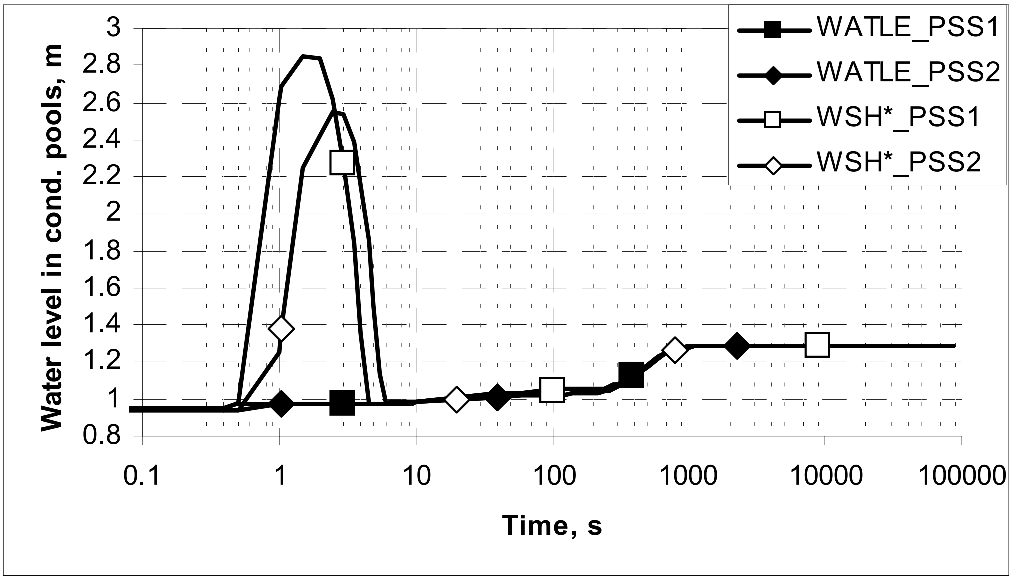

Figure 5: Water level behavior in the condensing pools of left (PSS1) and right (PSS2) ALT in case of MDBA

WATLE – water level from pools bottom calculated by water mass, WSH* – water surface position

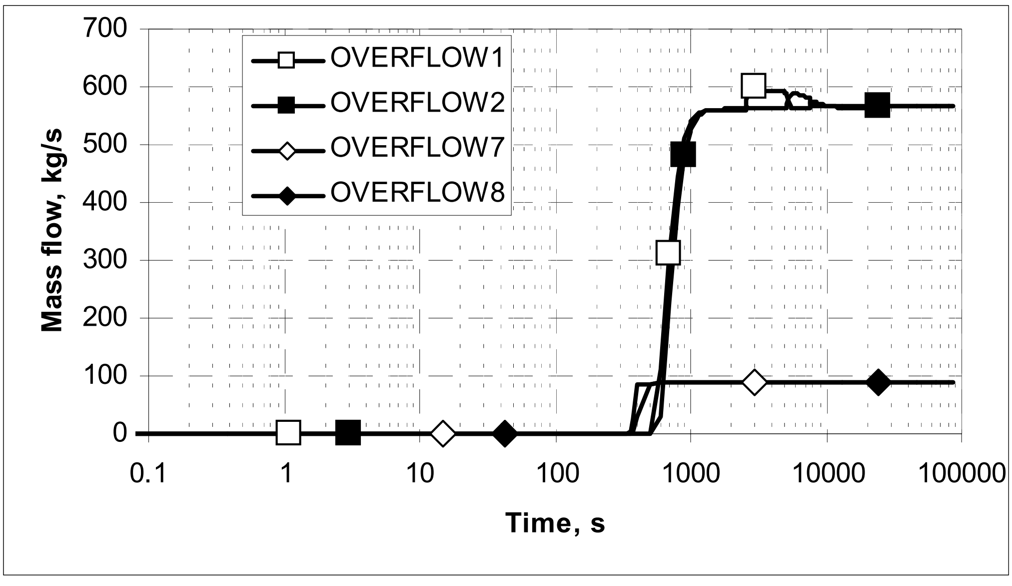

Figure 6: Water overflow from the condensing pools of left (OVERFLOW 1 and 7) and right (OVERFLOW 2 and 8) ALT in case of MDBA

Steam condensation and air carry over. Some alternative models of steam condensation (6 models) and gas carry over (7 models) are available in RALOC code in dependency of gas/water interface motion mode [3]. The following modes are available for the description of the gas/water interface motion:

- vent clearing;
- pool swell;
- steady state steam condensation with a small and further decreasing gas content;
- condensation oscillations – i.e. quasi-steady steam condensation and the movement of the steam-water interface from inside of the pipe to outside (bubble) and back.

The models with no gas carry over and no condensation were defined in input deck for the vents clearing stage. Generally, gas carry over starts after vent clearing and when bubbles reach the water surface. Gas carry over after the delay time using semi- empirical equation was selected in the input deck for pool swell stage. The steam behavior during this stage was simulated by simultaneous condensation model of incoming steam. The condensation and gas carry over for steady state stage was calculated by orifice equation for homogenous, adiabatic, compressible, one-dimensional fluid flow. The smoothing of steam condensation and gas carry over by notches at bottom end of vent pipes was considered in the long-term steady state stage calculations. The calculated flow of the incoming air and steam through the condensing pools are presented in Figure 7 and Figure 8 respectively. The presented flow rates are the average value for one vent pipe, i.e. one value is calculated for each of the 924 vent pipes per ALS side. As it is shown in Figure 7 the air flow through the condensing pools starts approximately in 1 s after the accident start and lasts till 15 s through the left side ALT and till 60 s through the right ALT. After that almost no air is left in the dry well and the atmosphere in the compartments consists of steam and water droplets. The steam flow through the condensing pools ends in approximately 200 – 300 s after accident start when the CTCS reach its full capacity and the water level (Figure 5) increases to 1.3 m.

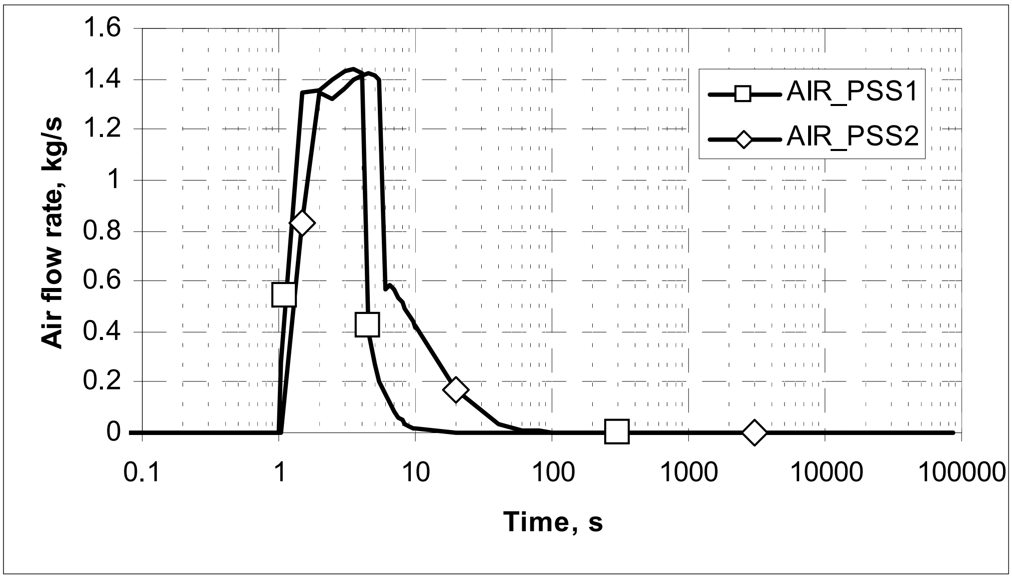

Figure 7: The airflow per one vent pipe through the condensing pools of left (PSS1) and right (PSS2) ALT in the case of MDBA

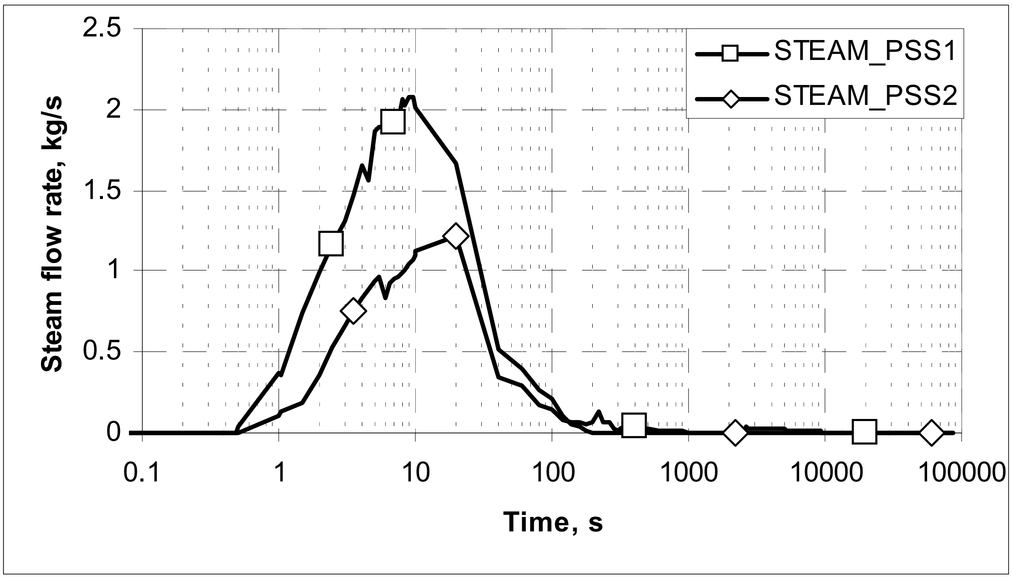

Figure 8: The steam flow rate per one vent pipe to the condensing pools of left (PSS1) and right (PSS2) ALT in the case of MDBA

The water temperatures in the condensing pools increase to about 70 ^oC after 200 s in left side pools and to about 60 ^oC after 300 s in the right side pools (Figure 9). The higher water temperature in the left side pools was calculated due to closer location of these pools to the break location (break was assumed in the left side of ALS). Water temperature in both ALS towers later reduces due to effective CTCS operation.

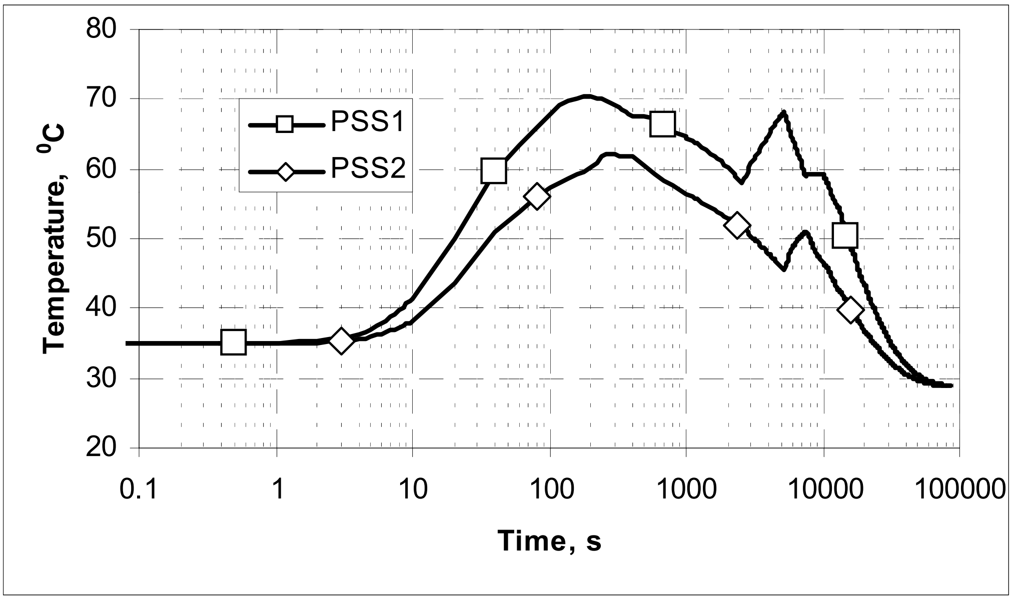

Figure 9: Behavior of water temperature in condensing pool of left (PSS1) and right (PSS1) ALT in case of MDBA

The maximum values of main thermalhydraulic parameters (as pressure, temperature) were calculated to be well below allowed design values [6], and, consequently, it is expected that ALS would perform their assigned functions in the case of MDBA as it is foreseen in the design.

Conclusion

The analytical investigations of phenomena related to the pressure suppression function fulfillment by the condensing pools of Ignalina NPP in the case of Maximum Design Basis Accident are performed. Analysis of the following phenomena related to the condensing pools behavior was performed employing code RALOC: 1) clearing of vent pipes inserted under the condensing pools water; 2) condensing pools water swelling and overflow; 3) steam condensation and air carry over.

Acknowledgment

The authors of this paper would like to acknowledge the access to the newest RALOC code version provided by the GRS. We are thankful to GRS experts for collaboration and for support performing analytical investigations by employing code RALOC. We also want to extend our thanks to the administration and technical staff of Ignalina NPP, for providing information regarding the operational procedures and the operational data.

Abbreviations

ALS	Accident Localization System
ALT	Accident Localization Tower
BWR	Boiling water Reactor
CTCS	Condensing Tray Cooling System
GRS	Gesellschsaft fur Anlagen-und Reaktorsicherheit mbH
LEI	Lithuanian Energy Institute
LOCA	Loss of Coolant Accident
MCC	Main Circulation Circuit
MCP	Main Circulation Pump
MDBA	Maximum Design Basic Accident
MSRV	Main Steam Relief Valve
NPP	Nuclear Power Plant
SDV-A	Steam Discharge Valve to ALT
TSRC	Top Steam Reception Chamber

References

1. Ignalina NPP Safety Analysis Report, 1996.
2. K. Almenas, A. Kaliatka, E. Uspuras. Ignalina RBMK-1500. A source book. Extended and updated version, Kaunas, 1998.
3. RALOC mod 4.0 cyclAE. User manual. Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH, 1995.
4. Application of the DRASYS Code for LOCA Analyses in the Accident Localisation System of Ignalina NPP, Unit 2. Report GRS-A-2348, 1996.
5. Technical Note. BMU/Bfs Project SR 2333. Long term analysis of the LOCA "Break of a Group Distribution Header with RALOC4". Berlin, 1999.
6. Technical Note. BMU/Bfs Project SR 2333. Long term analysis of the LOCA "Break of a Pressure Header with RALOC4". Berlin, 2000.
7. Ignalina Accident Localisation System Safety Case, 1998.
8. Fletcher C. D. et al. RELAP5/MOD3 code manual user's guidelines. Idaho National Engineering Lab., NUREG/CR-5535, January 1992.